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Physiochemical Assessment of Landfill Generated Leachates in Lagos, Nigeria

* Christopher N. Akujieze and [1]Imoukhuede M. Idehai
Department of Geology, Faculty of Physical Sciences,
University of Benin, Benin City, Nigeria.

*Corresponding author: chrisakujieze@gmail.com(+2847057665122)
[1]imoism@gmail.com (+2348025774515)

ABSTRACT - About 3.5 million tonnes of comingled municipal solid wastes (MSW) are dumped annually into the landfill areas of Lagos in Nigeria with a human population of about 21 million. Upon geo-bio-chemical processes, leachates are produced which are improperly collected and may be introduced to the environment with possible insidious effects on human health. Eight (8) composite leachates samples were collected from four (4) landfills in the megacity and tested for their physiochemical parameters in order to determine their suitability for discharge into agricultural soils and groundwater systems. Geological site investigation reveal that the landfills except Epe have significant attenuative clayey soil protection above groundwater, and can adsorb and/ or precipitate contaminants/ pollutants within its mass. Using ANOVA, juxtapositions of the $F_{calculated}$ with the $F_{critical}$ valuesrevealed a metal sequence of : Hg > Zn >As >Mn >Ni >K >Pb >Cr>Cd>Fe. Also, total alkalinity> total hardness> total acidity. All the measured anions had $F_{calculated}$ above $F_{critical}$ values and were in the hierarchy : Chloride> sulphate> phosphate>nitrate.. Mean concentrations were in the order : Fe>Cd>Cr>Pb>K>Ni=Mn>As>Zn>Hg. Fe also posted the highest value for standard deviation. Results of the ratios of the standard deviation to the means were in the sequence: Fe> Zn>K> Ni > Mn>Pb> Cr> Cd> Hg> As. The presence of arsenic above prescribed limits in the Epe leachate is a major concern because the lithology is sandy, and has a reported depth of about 3m to the unconfined aquifer that adjoins the Epe Lagoon. This expansive landfill is recommended for closure.

Keywords - ANOVA; attenuative capacity;composite leachates; unconfined aquifer.

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INTRODUCTION

Lagos has a current population of about 21 million people with a population density of 6,030/km^2. The daily generation per capita (GPC) is estimated at 0.63kg (Ogwueleka, 2009) thus generating about 13,230 tonnes of MSW. About 70% of this mass (about 9,261 tonne/ day) makes it to the landfill. The waste is made up of (in % volume) 45, 15, 5, 10, 5, 8, 4, 8 of vegetables, plastics , glass, paper, metals, fines, textiles and putrescibles respectively.It is important to note that the practice of landfill system as a method of waste disposal in many developing countries is usually far from standard recommendations (Adewole, 2009).

Deposition of comingled municipal solid wastes in the improperly engineered Lagos landfills triggers a number of geo-bio-chemical processes in the presence of significant precipitations that produces leachates. Given the absence of properly engineered leachate collection mechanisms in the landfills, the ensuing leachates mayenter soil and water systemsresulting in the despoliation of the environment.

Attenuative and impermeable soils such as clays/ lateritesare able to reduce the deleterious potentials of these complex fluids by processes of adsorption and / or precipitation. These soils were ubiquitous in all the Landfill areas of Lagos except at Epe.It is therefore imperative to have sufficient attenuative soil thicknesses to protect groundwater as instances have shown that even the lined (protected) landfills have been inadequate in the prevention of groundwater contamination (after

Lee and Lee, 2005). The Epe landfill was opened on the 12th of February, 2009. It is the largest landfill by size with an area of about 80 hectares. The location is about 5km on the outskirt of Epe town, along Ibeju/Lekki-Epe Expressway and about 1 km from the Epe Lagoon. A geotechnical study undertaken in the Epe Landfill in 2012 in order to determine the type, nature and mechanical strength properties of its soil;shows that the clearance between the groundwater and the sandy top soil averages 3 m in most areas. This study attempts to evaluate the concentrations of the physiochemical parameters of composite leachates from all the aforementioned landfills. The intent is to juxtapose these values with permissible standard for waste water in order to draw valuable environmental conclusions and /or recommendations in relation to the geology of the study areas.

LOCATION OF THE STUDY AREAS

The study was undertaken in four active landfills operated by the Lagos Waste Management Agency (LAWMA)in Lagos State of Nigeria. Lagos State lies approximately between longitudes $2^0$42' - $3^0$42' East and latitudes $6^0$22' - $6^0$52' North (Fig. 1-3). The southern boundary of the state lies along the Atlantic coastline while its northern and eastern boundaries are shared with Ogun State. On the western side the boundary is bordered by the Republic of Benin. Its size is about 3,577 km^2, has about 180km Coastline and is about 4.6m above sea level (A.S.L.) . It has about 22%water coverage consisting of rivers, lagoons, creeks and streams The population density was 4,193 persons/km^2 with a population growth rate of between 6-8% (Nigeria = 2.9%). The annual population growth is 600,000 (10 times that of New York City/ Los Angeles. The projected population was 20.19M (2010) & 24.5M (2015) (UNFPA, 2001). Lagos is the most populous city in Nigeria , the second fastest growing city in Africa and the seventh fastest growing city in the world.

GEOLOGICAL SETTINGS

The geology of the landfill areas is essentially that of the Oligocene to Pleistocene Coastal Plain Sands (CPS) except for that of Epe landfill area which is of Recent Littoral and Lagoonal Deposits (fig. 3 &4). The Recent sediments are underlain by the CPS while the CPS overlay a thick clay layer, the Ilaro Formation. The CPS consists of thick bodies of yellowish and white sands and gravels. The formation is poorly sorted and has local shale interbeds, lenses of clays and sandy clay with lignite.

The name Coastal Plains Sands was introduced by Tattam (1943) to indicate the extensive red earths and loose, ill-sorted sands underlying the Recent deposits of the Niger Delta and overlying the Eocene Bende-Ameki group. The name is now well—established in the stratigraphy of the Delta and it has been retained in the south—western coastal sedimentary basin, although the abundance of clays in the formation In this area do not make it entirely appropriate (Jones H.A, *et al*.1964). It consist of soft, very poorly sorted, clayey sands, pebbly sands, sandy clays, pockets of shale, and rare, thin lignites. They are indistinguishable in the field from much of the Ilaro Formation and from the basal continental beds of the Abeokuta Formation, which are similar lithologically, also unfossiliferous, and weather to the same, familiar red and brown sandy earths and clayey grits.

METHODS

Sample containers (high density polyethylene-HDPE bottles), used to sample for heavy metal analysis, were washed with metal free detergent and rinsed with tap water. They were soaked in 1M HNO_3 for 24 hours and later rinsed with demineralised water and kept in air-tight container till sampling period. All samplings were obtained as composite mixtures from different points at each site for proper representation. The sampling bottles were first rinsed with the leachate before sampling. The samples collected for heavy metals were preserved by the addition of concentrated HNO_3 (1 mg/l of leachate sample). This was to adjust the pH of the sample to less than 2, so as to arrest microbial activities and prevent loss of the metals by precipitation and adsorption. All samples collected were kept in ice chest to maintain them at a temperature below 4 °C during transference from the field to the laboratory. They were also kept in refrigerator under the laboratory condition till analyses were completed on them. The time between sampling and analyses of samples was kept short and between recommended times by the standard method. To avoid contamination, the nitric acid used in preservation was ultra pure grade (J. T. Baker, Ultrex). The methods of analysis were adopted for all parameters and were used for the examination of water and wastewater as recommended by the standard method (American Public Health Association -APHA, 1995).

The metal analysis were done by the digestion of 50ml of the sample using concentrated nitric acid to release the organic bound metals and those in particulate or those adsorbed on particulates. Analytical instruments included theAtomic Absorption Spectroscopy (AAS) and the DR 3800 spectrophotometer. Microsoft Excel (2007) software was used for statistical evaluation.

Fig. 1: World map showing Nigeria

Fig. 2: Map of Nigeria showing Lagos State

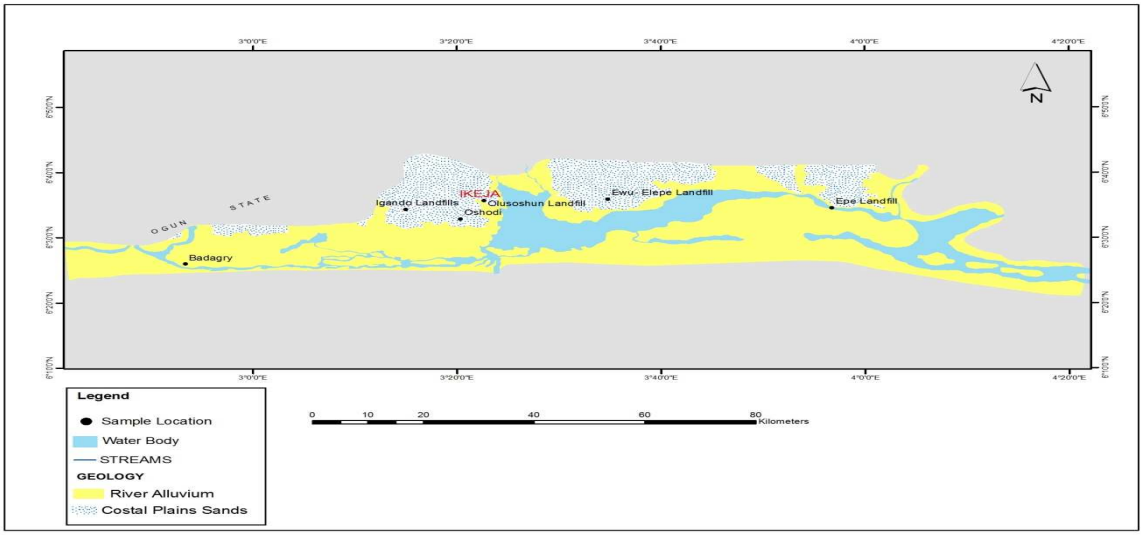
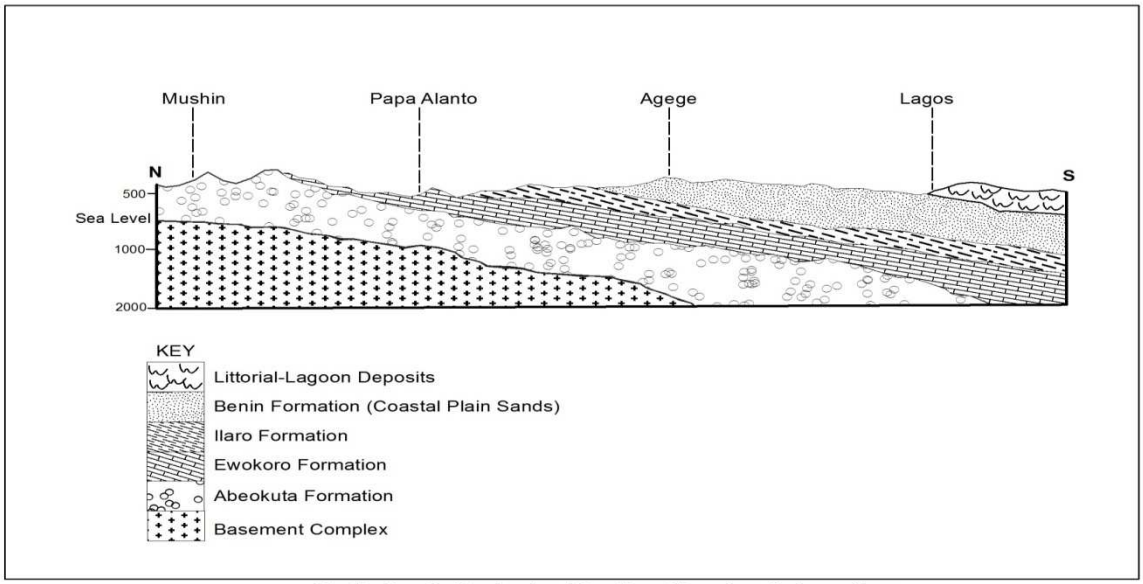


Fig. 3: Map of the geology of Lagos State showing the landfill locations and other areas.



North-South Geological Section Showing Sub-surface Stratigraphy of Lagos Area and parts of South Western Nigeria (Modified from Jones and Hockey 1964)

Fig.4: N- S geological section showing the major geological formations in the Lagos Area (after Jones and Hockey, 1964)

RESULTS AND DISCUSSIONS.

Shortly after MSW is landfilled, the organic components start to undergo biochemical reactions. In the presence of atmospheric air (that is near the surface of the landfill), the natural organic compounds areoxidized aerobically, a reaction that is similar to combustion because the products are carbon dioxide andwater vapour (Akujieze and Idehai, 2014).

Across the composite leachates in the landfills, the concentration of pH, chloride, phosphate, K, Mn, Zn, Ni, & Hg were all within applied permissible limits (fig.5-22). Nitrate concentrations were within acceptable limits except at Olusosun. This may be due to the combined effects of open faecal discharge and the volume of septic tanks within the vicinity. The observed Cd contents were in tandem with the limits of 1mg/l devised by LASEPA &FEPA. Notwithstanding, none of the composite leachates met with the German standard of 0.1mg/l. The lead (Pb) concentrations were all below the FEPA limit of 1mg/l. However, leachate from Ewu-Elepe and Soluos exceeded the German standard of 0.5mg/l. Unlike the other leachates, the Epe leachates were within the German standard of 0.5mg/l for Cr. Nonetheless, all the collected Cr concentration were within the FEPA standard of 1mg/l. The TSS, EC and As concentrations were above all the assessment standards. DO contents were also unacceptable except at portions of Ewu-Elepe and this indicates that the preponderance of waste loads in the leachates do not favour the existence of biota.

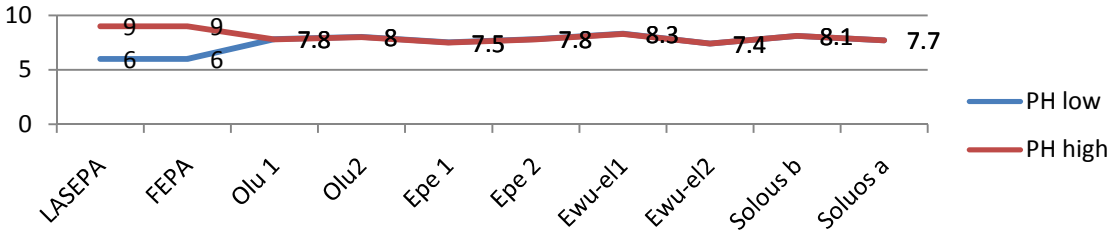


Fig. 5: Comparison of the pH concentrations of the composite leachates with standards.

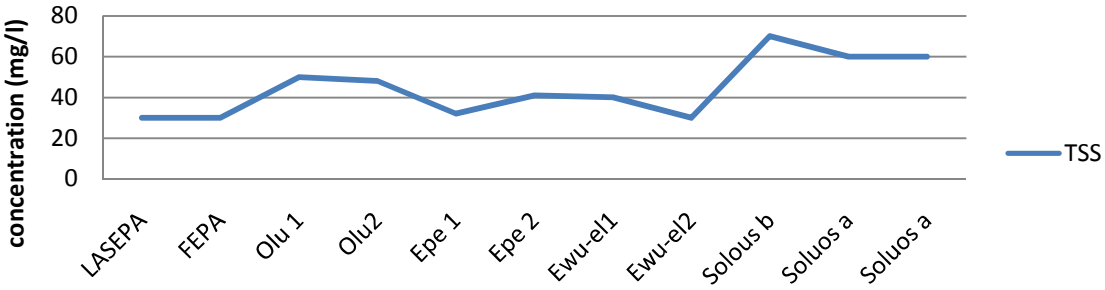


Fig. 6: Comparison of the TSS concentrations of the composite leachates with standards.

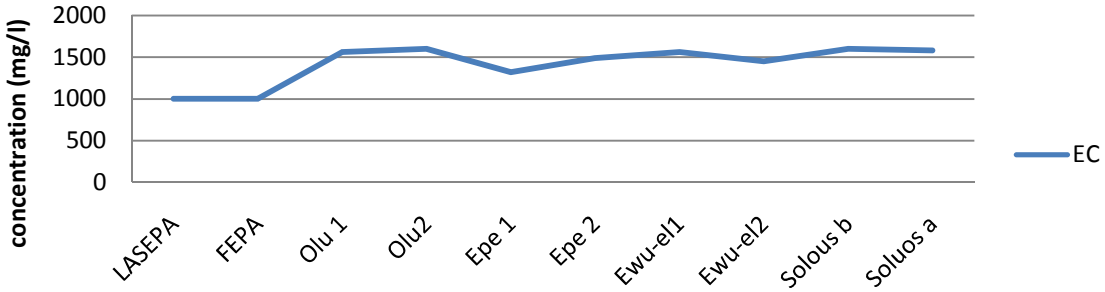


Fig. 7: Comparison of the EC concentrations of the composite leachates with standards.

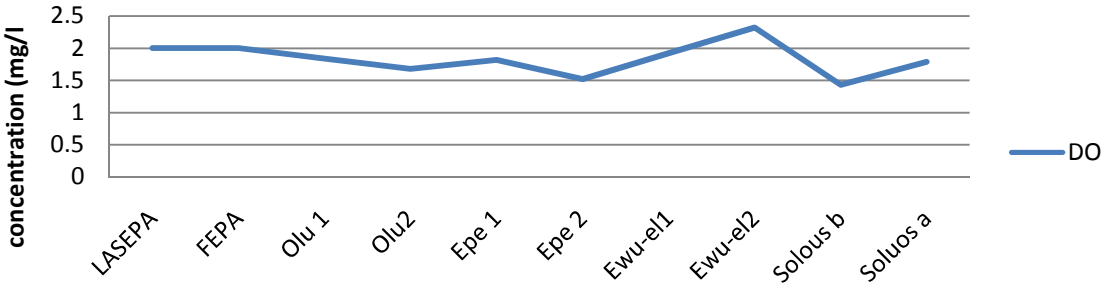


Fig. 8: Comparison of the DO concentrations of the composite leachates with standards.

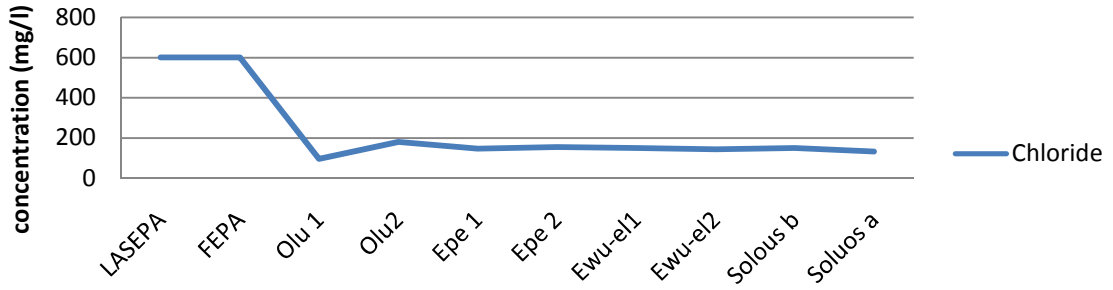


Fig. 9: Comparison of the chloride concentrations of the composite leachates with standards.

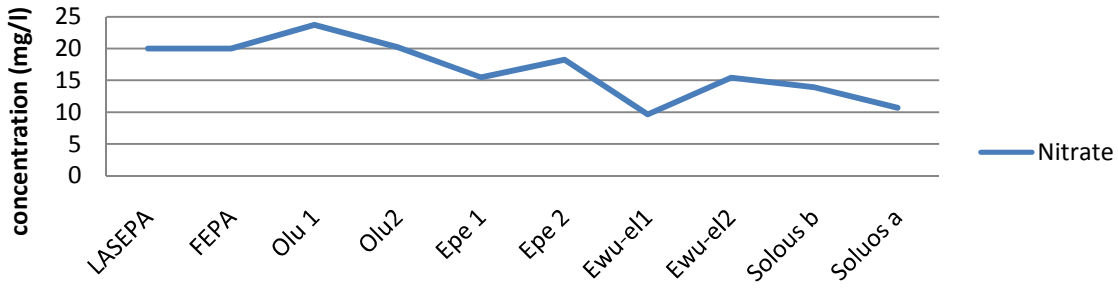


Fig. 10: Comparison of the nitrate concentrations of the composite leachates with standards.

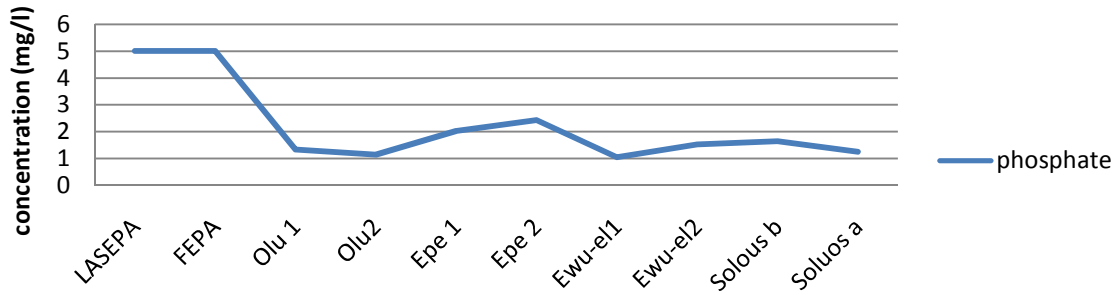


Fig. 11: Comparison of the phosphate concentrations of the composite leachates with standards.

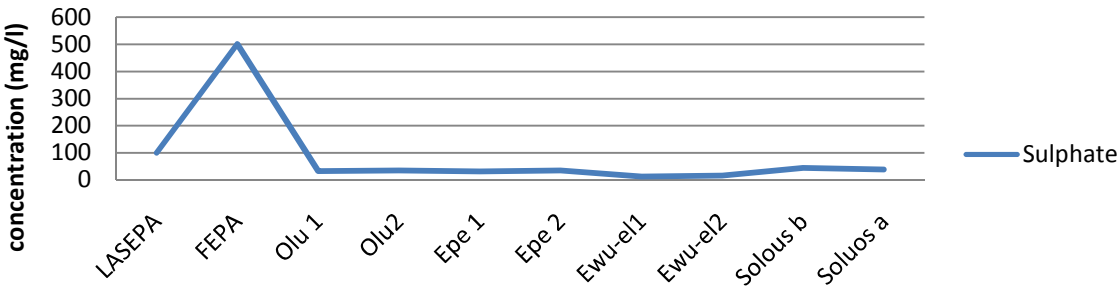


Fig. 12: Comparison of the sulphate concentrations of the composite leachates with standards.

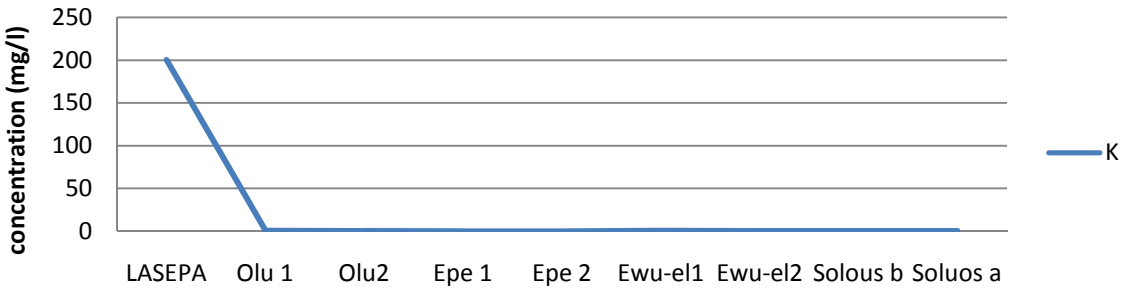


Fig. 13: Comparison of the potassium concentrations of the composite leachates with standards.

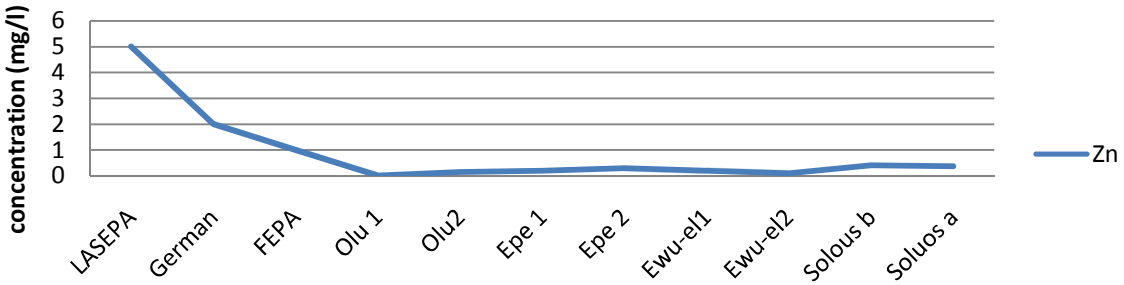


Fig. 14: Comparison of the zinc concentrations of the composite leachates with standards.

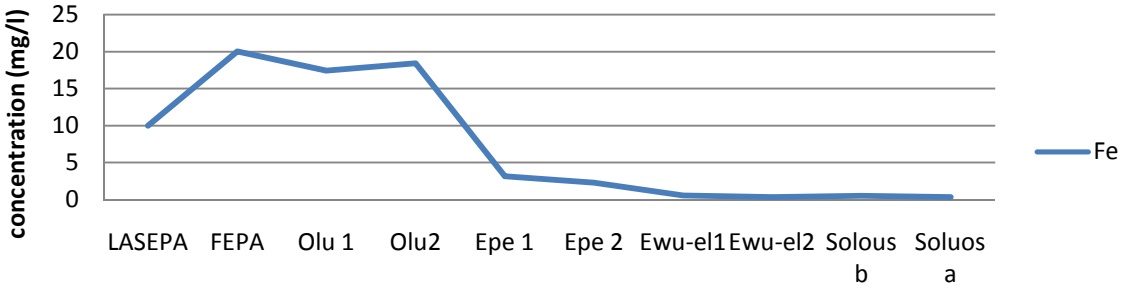


Fig. 15: Comparison of the iron concentrations of the composite leachates with standards.

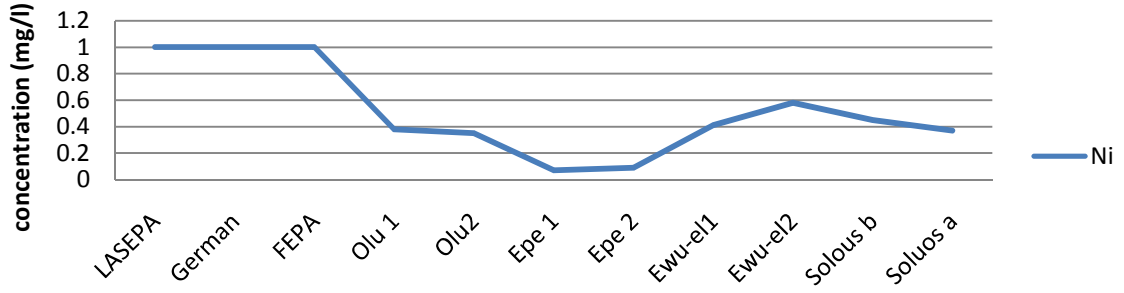


Fig. 16: Comparison of the nickel concentrations of the composite leachates with standards.

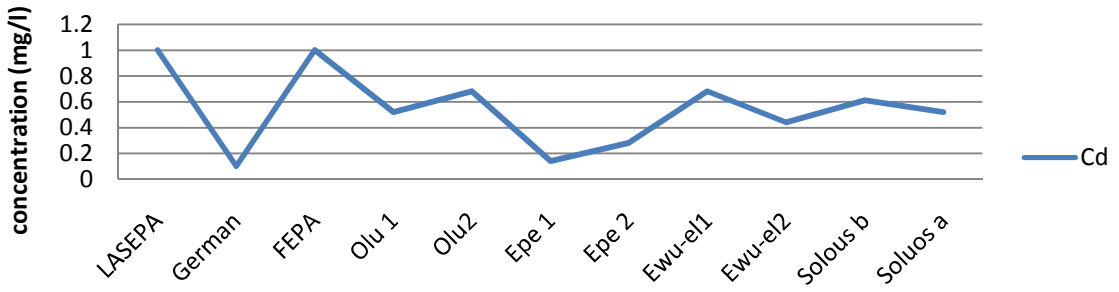


Fig. 17: Comparison of the cadmium concentrations of the composite leachates with standards.

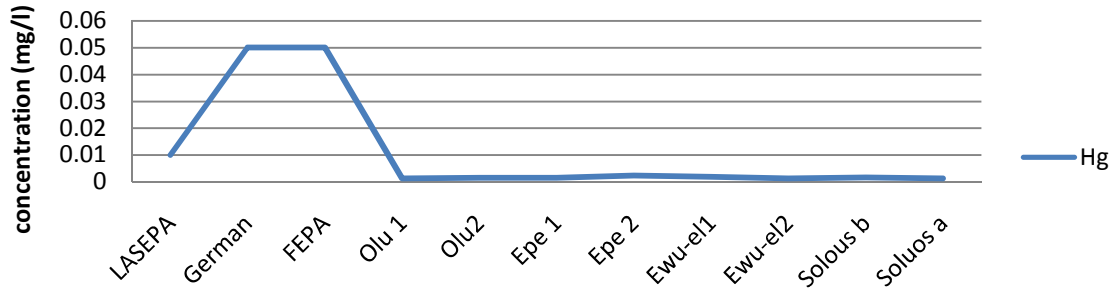


Fig. 18: Comparison of the mercury concentrations of the composite leachates with standards.

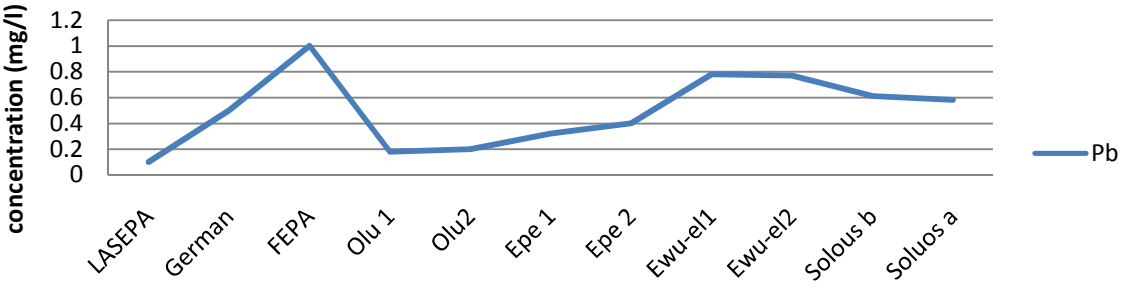


Fig. 19: Comparison of the lead concentrations of the composite leachates with standards.

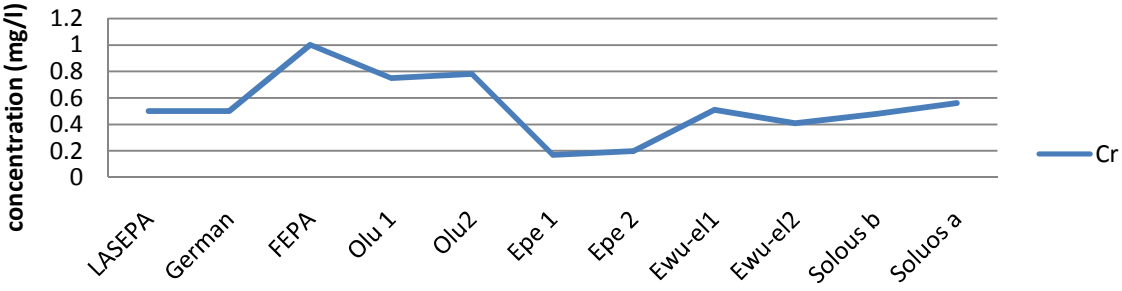


Fig. 20: Comparison of the chromium concentrations of the composite leachates with standards.

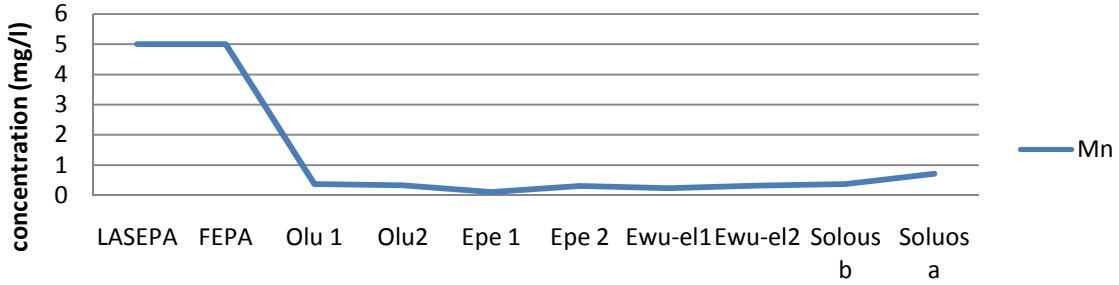


Fig. 21: Comparison of the manganese concentrations of the composite leachates with standards.

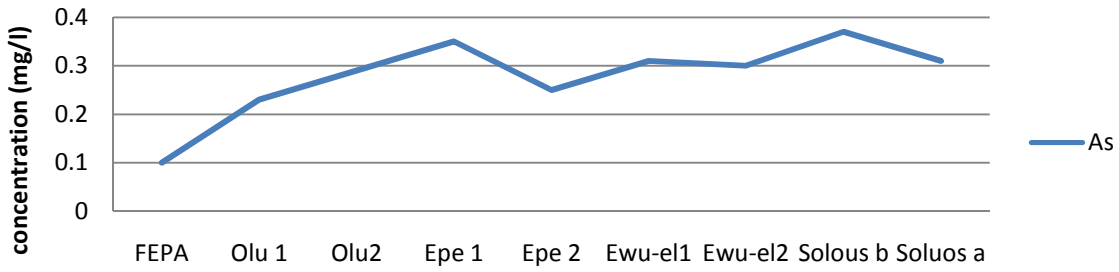


Fig. 22: Comparison of the arsenic concentrations of the composite leachates with FEPA standard.

Applying analysis of variance (ANOVA) at 95% confidence limit (fig. 23-25), the null hypothesis H_0(implying that the means across the landfill leachates are the same and that the results obtained occurred by chance) was rejected for all the metals except Fe. This can partly be explained by the interacting contributions from the lithology of the landfill areas (which vary from Fe-rich soils of the Coastal Plain Sands areas to poorly Fe enriched sands and silts of the Recent Sediments of Epe), and the varying quantities of iron-bearing scraps deposited in the landfill. Therefore, Fe is not a distinctive feature of the analyte metals in this study. Hg had the highest $F_{calculated}$ value among the metals. This indicates that the disparities in the means of the mercury content across the landfill is the most certified to be true. Juxtapositions of the $F_{calculated}$ with the $F_{critical}$ revealed a metal sequence of : Hg > Zn >As >Mn >Ni >K >Pb >Cr>Cd>Fe. Also, total alkalinity> total hardness> total acidity All the anions had $F_{calculated}$ above $F_{critical}$ values and were in theorder: Chloride> sulphate> phosphate>nitrate.

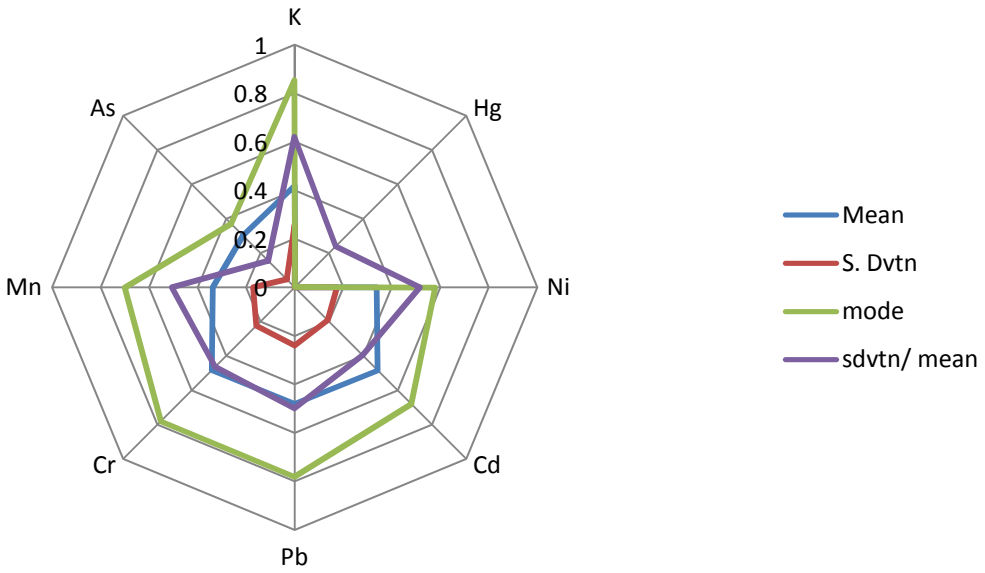


Fig. 23a: Comparison of central tendencies among the metals.

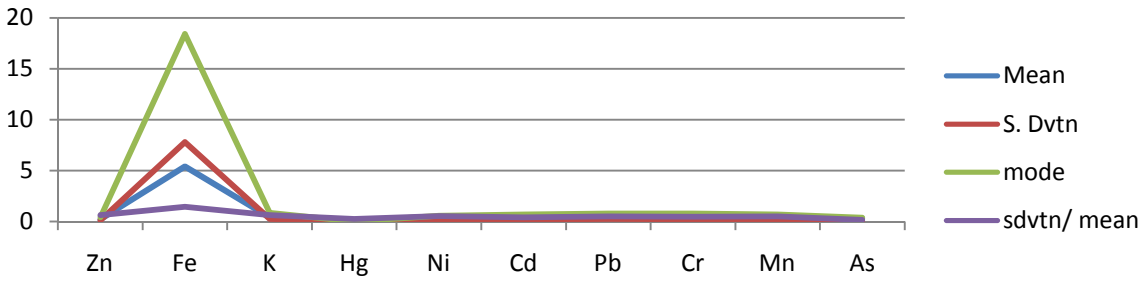


Fig. 23b: Comparison of central tendencies among the metals.

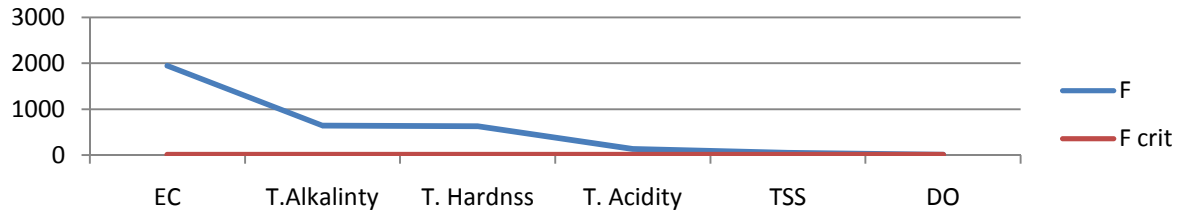


Fig. 24a : Plots of $F_{calculated}$ Vs. $F_{critical}$ (ANOVA)

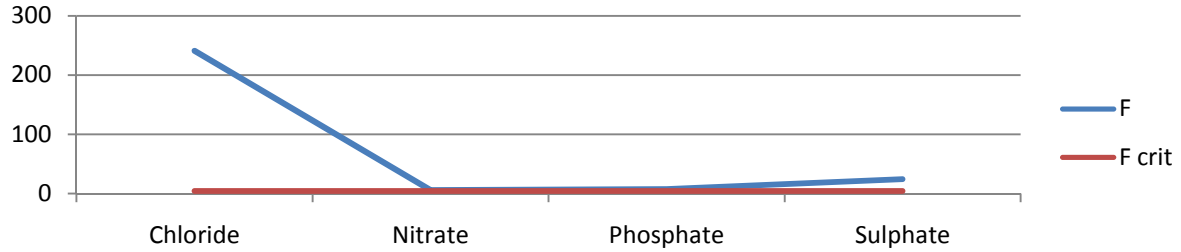


Fig. 24b : Plots of $F_{calculated}$ Vs. $F_{critical}$ in the anions (ANOVA)

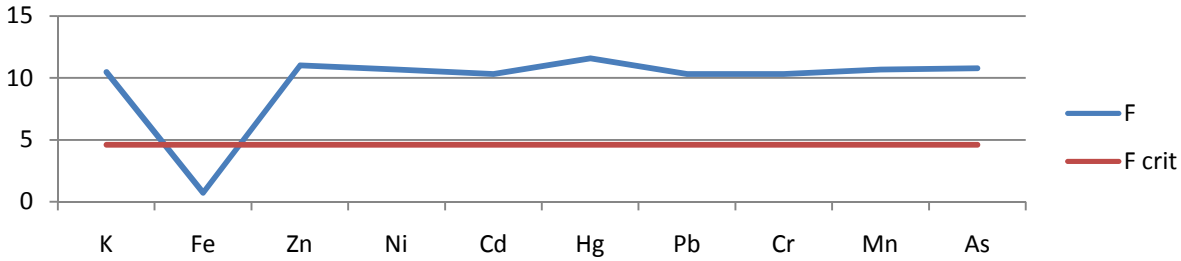


Fig. 25 : Plots of $F_{calculated}$ Vs. $F_{critical}$ in the cations (ANOVA).

The pH values are supportive of the null hypothesis, and like Fe, seemessentially occasioned by chance, and therefore spurious. By implication, the reported pH and Fevalues cannot be used to draw conclusive empirical evaluation, as they are highly susceptible to shocks and fluctuations.Notwithstanding, the statistical sequence and concentrations of the pH are in harmony and typifies the alkaline nature of the leachates and also points to the age of the leachates since leachates often progress from acidic to alkaline fluids as time progresses. Conversely, the EC values allow a disregard of the null hypothesis.

The black colour of the leachate in conjunction with the lack of sunlight inside the leachate reservoir makes the oxygen levels to decrease markedly leading to the appeasement of anaerobic conditions. Under this condition, the nitrate is attenuated by the process of biological denitrification with nitrate reduction to gaseous nitrogen (Baghi, 1993). Because of this, the higher the time that the leachate is stored before percolation, the higher will be the attenuation. With the decrease of the carbon sources and bacterial population, the retention of nitrate by the soil begin to decline, until the moment when the levels before and after percolation tend to the same value.(Junqueira F.F. *et al*, 2000).

The ageing of a landfill is accompanied by increased quantity of leachates. Leachates generated in the initial period of waste deposition (up to 5 years) in landfills have pH-value range of 3.7 to 6.5 indicating the presence of carboxylic acids and bicarbonate ions. With time, pH of leachate becomes neutral or weakly alkaline ranging between 7.0 and 7.6. Landfills exploited for long period of time give rise to alkaline leachate with pH range of 8.0 to 8.55 (Slomczynska and Slomczynski, 2004; Longe and Balogun, 2010). The pHs of the composite leachates from the Lagos landfills are in this range.

Fe had the highest modal concentration at 18.41mg/l while Hg had the lowest modal concentration at 0.00235mg/l. In order of modal concentration, Fe>K>Pb=Cr>Mn>>Cd>Ni>Zn>As>Hg. Similarly, in terms of means: Fe>Cd> Cr>Pb>K>Ni=Mn>As>Zn>Hg.Studies by Sposito in 1989 posited that mercury is the most strongly adsorbed of the heavy metals ; this being the probable reason for its generally very low concentration occurrence in groundwater. This is further buttresses here by the out-plays of the concentrations of Hg across the leachates and the statistical evaluation that Hg is the most significant and reliable parameter among the measured cations. Fe also posted the highest value for standard deviation. Results of the fractional ratio of the standard deviation to the means were in the sequence: Fe> Zn>K> Ni > Mn>Pb> Cr> Cd> Hg> As. This implies that the reverse order of the aforementioned shows greater proximity to the obtained means. For instance, As has the least deviation when compared with the metals. With a mean of 0.30125, standard deviation of 0.04643 and mode of 0.37mg/l ; the arsenic concentration across

the landfills is a present concern given its imbuement in the leachates over the prescribed limit of 0.1mg/l. Furthermore,with an As mean concentration of 0.3mgl/l in Epe which has a reported subsisting unconfined aquifer at about 3m depth and which adjoins a nearby Lagoon, continuous operations of this landfill poses serious environmental concerns.Anthropogenic arsenic contamination occurs where arsenic-based pesticides have been applied. Arsenic mobilisation is also induced where dewatering of aquifers has resulted in a lowering of the groundwater table promoting pyrite oxidation. The application of arsenic-based pesticides may be an accessory source for arsenic. Although the mobility of arsenic in top soils is low, leaching over long timescales may increase arsenic concentrations in groundwater under arable lands as in Epe landfill area.The adsorption of As is enhanced in the presence of freshly precipitated metal hydroxides, and decreases with ageing of mineral surfaces. Weaker adsorption of arsenic is expected when competing anions such as phosphate, bicarbonate and silicate, are present in the groundwater. The mobility of arsenic is also controlled by precipitation/ dissolution reactions. Organic forms of arsenic may be present in groundwater, but are generally negligible. The input of fresh organic carbon or itsdegradation products may quickly mobilise arsenic due to carbon-driven reduction of Fe-hydroxidesand/ or desorption by carbonate ions. Desorption from Fe-hydroxides bycompetitive dissolved organic matter has been demonstrated by Bauer & Blodau (2005).

A 2002 estimate found that dental amalgam waste from dental offices is a major mercury-containing input to MSW, contributing a significant amount of the total mercury in solid waste (Aucott, 2006). Mercury is one of the most strongly adsorbed metal and is probable the reason for its generally very low concentration occurrence in groundwater. This was again buttressed by results in this study

As it relates to metal contamination, Prudent, *et al*.(1996), found that approximately 50% of the cadmium load was in the form of plastics as pigments or stabilizing agents. However, more recent data indicate that the increasing use of cadmium in batteries means that perhaps 75% of the cadmium in MSW today is in the form of batteries. Chromium was mostly in the form of non-ferrous metal scrap but perhaps 25% of the load in waste was in leather. Nickel was found to be mostly associated with scrap metal, and with glass and fine particles. Zinc and lead were mostly in the form of scrap metal, but also were found associated with fine particles. 65% of the lead in products discarded in MSW was in the form of lead-acid batteries, 30% was in consumer electronics, and 4% was in glass, ceramics, and plastics. Much of the mercury in waste is believed to exist primarily within disposed products including batteries, fluorescent bulbs, thermostats and other switches, and measuring and control devices such as thermometers.

Although the local geology favours a reasonable iron content in the leachates (Longe *et al*., 1987), concentration of Fe in the leachate may also be associated with iron-bearing scraps dumped in the landfills.

Although none of the landfills is neither sanitary nor properly engineered, wastes in them(except Epe) are dumped on clayey / lateritic soils. With sufficient soil thickness, this offers protection to groundwater by attenuation arising from adsorption and/ or precipitation. However, this protection has been compromised in some areas with excavation of large volumes of soil masses. For siting new landfills, the potential for pollution of groundwaters could be drastically minimized by maintaining an adequate buffer zone between the landfill and the property line of the adjacent property. A buffer zone of three miles in the direction of groundwater flow is most appropriate (Lee *and Lee,* 2005).

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CONCLUSIONS

The results of the physiochemical analyses of the Lagos landfill leachates show that most of the measured physiochemical parameters are within standards devised by FEPA, LASEPA, etc. However, the concentrations of arsenic in the Epe leachates is a huge concern given its porous sandy lithology, shallow unconfined aquifer and proximity to the expansive Epe/ Lekki Lagoon. Therefore, the Epe landfill should be closed and environmental remediation processes commenced therein. Furthermore, emphases should be placed on the improvement of leachates collection mechanisms within the other landfills to curtail pollution. Ensuring sufficient attenuative soil thickness above the groundwater is an imperative to guard against environment despoliation.

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